

CAPACITIVE HIGH-SIDE SWITCH DRIVER FOR A POWER CONVERTER

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a high-side switch driver, and more particularly relates to a driver circuit for driving the high-side switch of a power converter.

Description of the Prior Art

Many commonly used power converters utilize bridge circuits to regulate a voltage source in response to a load. Some of these power converters include power supplies and motor drivers.

The bridge circuits used by these power converters are normally built from a pair of switching devices connected in series across the voltage source. The switching devices include a high-side switch and a low-side switch. The high-side switch is connected to the voltage source while the low-side switch is connected to the ground reference. A common node between the high-side switch and low-side switch is coupled to the load. The switches are generally transistor-devices (MOSFET, IGBT, etc). The switches are controlled to alternately conduct, so that the common node will periodically swing in between the voltage source and the ground reference. When the high-side transistor is turned on, the voltage of the common node will rapidly shift to the voltage level of the voltage source. When the high-side transistor is fully turned on, the bridge circuit will operate in low-impedance mode. To turn on the high-side transistor, the gate drive voltage must exceed the voltage of the voltage source. Thus,

the gate-to-source voltage of the high-side transistor will be floated with respect to the ground reference.

FIG. 1 demonstrates a technique that employs a pulse transformer 5 to create a floating voltage for driving a high-side transistor 10. However, the design of the pulse transformer 5 suffers from two disadvantages. First of all, its size is relatively large. Second, the pulse transformer 5 will require a substantially higher driving current due to magnetizing-current consumption.

FIG. 2 shows another prior-art bridge circuit using a bootstrap capacitor 30 and a charge-pump diode 40 to create a floating voltage for driving a gate of a high-side transistor 10. Switching on a transistor 45 will pull down the voltage at the gate of the high-side transistor 10 to the ground reference. The gate voltage of the high-side transistor 10 will be pulled down via a diode 42. This will turn off the high-side transistor 10. Once the high-side transistor 10 is turned off and a low-side transistor 20 is turned on, the floating voltage of the bootstrap capacitor 30 is charged up to a bias voltage V_B via the charge-pump diode 40. Switching off the transistor 45 will turn on the high-side transistor 10 by conducting the floating voltage to the gate of the high-side transistor 10 via a transistor 41. The drawback of this circuit is that the gate voltage level might not be sufficient to ensure proper operation. Since the bootstrap capacitor 30 is charged via the low-side transistor 20, its charge time and the bootstrap voltage may decrease to an unacceptable level due to the reduced duty cycle of the low side transistor 20. Furthermore, the voltage drops across the diode 40 and the transistor 41 will cause the gate voltage level of the high-side transistor 10 to fall.

Recently, various techniques have been proposed for generating the required gate voltage for the high-side transistor in a more reliable manner. One such technique

appears in U.S. Patents **5,381,044** (Zisa, Belluso, Paparo), **5,638,025** (Johnson), and **5,672,992** (Nadd).

The drawback of these prior-arts is the need for a switch-off transistor such as the transistor **45**. The prior-art bridge circuits listed above use something like the transistor **45** of FIG. 2 to turn off the high-side transistor. This switch-off transistor must be manufactured according to a high-voltage process, in order to be safely used in high-voltage applications (200 volts or more). To be integrated into a silicon chip, this high-voltage transistor requires a relatively thick coat of oxide and silicon. Furthermore, the parasitic capacitance of this high-voltage transistor will slow down the slew rate of the switching signal, thus resulting in significant high-side transistor switching losses. Therefore, these prior-arts are not suitable for high-voltage applications, or for high-speed applications.

To remedy this shortcoming, a technique using a boost converter is proposed in U.S. Patent **6,344,959** (Milazzo). The boost converter is essentially a voltage doubling circuit. While this technique generates a more reliable gate voltage to drive the high-side transistor, it requires an additional switching element and other circuitry. This increases the cost and complexity of the driving circuit. Moreover, severe noise will be generated by the voltage source and the ground reference, due to high frequency charging and discharging of the voltage doubling capacitor in the charge pump.

The objective of the present invention is to provide a high-side switch driver for high-voltage and high-speed applications that overcome the drawbacks of prior art high-side switch drivers.

SUMMARY OF THE INVENTION

The capacitive high-side switch driver according to the present invention includes an inverter and two totem-pole buffers. The switch driver controls the totem-pole buffers in response to an input signal, in such a manner that they alternately conduct with complementary duty cycles. The outputs of the two totem-pole buffers drive two high-voltage capacitors. These high-voltage capacitors are further coupled to the input of a high-side circuit. The high-side circuit comprises a comparator, a programmable load, an under-voltage protector, and a drive-buffer for driving a high-side transistor. The high-side circuit further consists of a charge-pump diode and a bootstrap capacitor.

When the low-side transistor is turned on, the bootstrap capacitor is charged to drive the high-side transistor. The two totem-pole buffers and the two high-voltage capacitors generate differential signals to drive the comparator, and further charge the bootstrap capacitor via a bridge-rectifier. The bootstrap capacitor is used to supply power for the high-side circuit.

One objective of the present invention is to provide protection against low gate-voltage levels. The under-voltage protector enables the drive-buffer whenever the floating voltage exceeds the start-threshold voltage, and disables the drive-buffer whenever the floating voltage drops below the stop-threshold voltage. The under-voltage protector further protects the high-side circuit from an insufficient supply voltage and ensures a sufficient gate-voltage level for the high-side transistor.

Another objective of the present invention is to provide a high-side switch driver with improved noise immunity. This is accomplished by connecting a programmable load in parallel to the input of the comparator. The programmable load provides a variable impedance to prevent noise interference. Furthermore, the two totem-pole

buffers produce a differential voltage across the input of the comparator. This differential voltage further strengthens the noise immunity of the high-side circuit, so that it will be suitable for use in high-voltage applications.

To raise the floating voltage and improve the efficiency of the high-side switch driver, the bias voltage charges the bootstrap capacitor when the low-side transistor is turned on. The differential signals also provide additional power via the bridge-rectifier.

The capacitive high-side switch driver according to the present invention overcomes the drawbacks of prior-art high-side switch drivers. In particular, the present invention provides a capacitive high-side switch driver that is suitable for high-voltage and high-speed applications. Moreover, the capacitive high-side switch driver according to the present invention is substantially more efficient and has stronger noise immunity than prior-art switch drivers.

It is to be understood that both the foregoing general description and the following detailed description are exemplary, and are intended to provide further explanation of the invention as claimed.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings are included to provide a further understanding of the invention, and are incorporated in and constitute a part of this specification. The drawings illustrate embodiments of the invention and, together with the description, serve to explain the principles of the invention.

FIG. 1 shows a high-side switch driver using a pulse transformer.

FIG. 2 shows a conventional high-side switch driver.

FIG. 3 shows the schematic circuit of a capacitive high-side switch driver

according to the present invention.

FIG. 4 shows a programmable load according to a preferred embodiment of the present invention.

FIG. 5 shows an under-voltage protector according to a preferred embodiment of the present invention.

FIG. 6 shows a schematic circuit of the buffer, for reference purposes.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 3 shows a capacitive high-side switch driver according to the present invention. The capacitive high-side switch driver comprises an inverter 53, a totem-pole buffer 50, and a totem-pole buffer 55. The totem-pole buffers 50 and 55 are controlled to alternately conduct in response to an input signal S_{IN} , so that their duty cycles are complementary. The totem-pole buffer 50 is driven by the input signal S_{IN} . The input signal S_{IN} drives the totem-pole buffer 55 via the inverter 53. An output of the totem-pole buffer 50 drives a capacitor 91. An output of the totem-pole buffer 55 drives a capacitor 92. A high-side circuit 60 has an output terminal for driving a high-side transistor 10, wherein capacitors 91 and 92 are coupled to an input of the high-side circuit 60. The totem-pole buffers 50 and 55 and the capacitors 91 and 92 generate differential signals and produce a differential voltage across the input of the high-side circuit 60.

A charge-pump diode 40 and a bootstrap capacitor 30 are connected in series. An anode of the charge-pump diode 40 is connected to a bias voltage terminal V_B . A negative terminal of the bootstrap capacitor 30 is connected to a source of the high-side transistor 10. A cathode of the charge-pump diode 40 and a positive terminal of the

bootstrap capacitor **30** are tied together. When a low-side transistor **20** is turned on, the bias voltage **V_B** will charge the bootstrap capacitor **30** and create a floating voltage to supply power for the high-side circuit **60**. A rectifier **81**, a rectifier **82**, a rectifier **83**, and a rectifier **84** form a bridge-rectifier having an input terminal and an output terminal. The input terminal of the bridge-rectifier is connected to the input of the high-side circuit **60**. The output terminal of the bridge-rectifier is connected in parallel to the bootstrap capacitor **30**. The differential signals further charge the bootstrap capacitor **30** via the bridge-rectifier to supply power for the high-side circuit **60**.

The high-side circuit **60** further comprises a comparator **70** and a drive-buffer **75**. An input of the comparator **70** is connected to the input of the high-side circuit **60**. An output of the drive-buffer **75** drives a gate of the high-side transistor **10**. An input of the drive-buffer **75** is connected to an output of the comparator **70**. The comparator **70** has a turn-on threshold. When the differential voltage across the inputs of the comparator **70** exceeds the turn-on threshold, the comparator **70** will output a logic-high signal. A programmable load **100** is connected in parallel with the inputs of the comparator **70**. The programmable load **100** provides variable impedance in response to the magnitude of the voltage at the output of the comparator **70**. An input of the programmable load **100** is connected to the output of the comparator **70**. When the voltage at the output of the comparator **70** is logic-low, the programmable load **100** will generate low impedance. When the voltage at the output of the comparator **70** is logic-high, the impedance of the programmable load **100** will increase in proportion to the length of the logic-high output period of the comparator **70**.

The capacitive high-side switch driver according to present invention further includes an under-voltage protector (UVP) **200** connected in parallel with the bootstrap

capacitor 30. The under-voltage protector 200 is used to detect the floating voltage of the bootstrap capacitor 30. The output of the under-voltage protector 200 is connected to an enable terminal of the drive-buffer 75. The under-voltage protector 200 will enable the drive-buffer 75 whenever the floating voltage exceeds a start threshold voltage. Furthermore, the under-voltage protector 200 will turn off and/or disable the drive-buffer 75 whenever the floating voltage goes below a stop-threshold voltage. A resistor 65 is connected from the output of the drive-buffer 75 to a negative terminal of the bootstrap capacitor 30. The resistor 65 is used to shut off the high-side transistor 10 when the drive-buffer 75 is disabled.

FIG. 4 shows a programmable load 100 according to a preferred embodiment of the present invention. The programmable load 100 has a pl-ground terminal connected to the negative terminal of the bootstrap capacitor 30. The programmable load 100 further includes a voltage terminal connected to the positive terminal of the bootstrap capacitor 30. The programmable load 100 further comprises an inverter 110, a constant current source 120, a transistor 123, a capacitor 125, three buffers 151, 152 and 153, three transistors 171, 172 and 173, and three resistors 191, 192 and 193.

An input of the inverter 110 is connected to the output of the comparator 70. The transistor 123 has a gate connected to an output of the inverter 110. A source of the transistor 123 is connected to the pl-ground terminal of the programmable load 100. The constant current source 120 is connected to a drain of the transistor 123. The capacitor 125 is connected from the drain of the transistor 123 to the pl-ground terminal. The buffer 151, the buffer 152, and the buffer 153 have a first input-threshold, a second input-threshold, and a third input-threshold respectively. An input of the buffer 151, an input of the buffer 152, and an input of the buffer 153 are tied to the drain of the

transistor 123. The transistor 171 and the resistor 191 are connected in series, and further connected in parallel with the inputs of the comparator 70. The transistor 172 and the resistor 192 are connected in series, and further connected in parallel with the inputs of the comparator 70. The transistor 173 and the resistor 193 are connected in series, and further connected in parallel with the inputs of the comparator 70. A gate of the transistor 171 is connected to an output of the buffer 151. A gate of the transistor 172 is connected to an output of the buffer 152. A gate of the transistor 173 is connected to an output of the buffer 153.

When the output of the comparator 70 becomes logic-high, the constant current source 120 will start to charge the capacitor 125. When the voltage of the capacitor 125 exceeds the first input-threshold voltage, the transistor 171 will be shut off. When the voltage of the capacitor 125 exceeds the second input-threshold voltage, the transistor 172 will be shut off. When the voltage of the capacitor 125 exceeds the third input-threshold voltage, the transistor 173 will be shut off. Thus, the impedance of the programmable load 100 is increased in proportion to the voltage of the capacitor 125. In this manner, the impedance of programmable load 100 is also increased in proportion to the length of the logic-high output period of the comparator 70.

FIG. 5 shows an under-voltage protector 200 according to a preferred embodiment of the present invention. A voltage $V+$ is supplied from the positive terminal of the bootstrap capacitor 30. The negative terminal of the bootstrap capacitor 30 is connected to a uv-ground reference. Two resistors 231 and 232, and two zener diodes 210 and 220 are connected in series. The voltage $V+$ is supplied to the zener diode 210. The resistor 232 is connected to the uv-ground reference.

An n-transistor 250 has a gate connected to the junction of the zener diode 220 and

the resistor 231. A source of the n-transistor 250 is connected to the uv-ground reference. The drain of the n-transistor 250 is connected to a gate of a p-transistor 271. A source of the p-transistor 271 is connected to a cathode of the zener diode 210. A drain of the p-transistor 271 is connected to the junction of the zener diode 210 and the zener diode 220. A resistor 240 is connected in parallel between the gate and the source of the p-transistor 271. The drain of the n-transistor 250 is further connected to an input of a buffer 290. An output of the buffer 290 is further connected to the enable terminal of the drive-buffer 75. The output of the buffer 290 drives a gate of an n-transistor 272. A drain of the n-transistor 272 is connected to the junction of the resistor 231 and the resistor 232. A source of the n-transistor 272 is connected to the uv-ground reference. The voltages of the zener diodes 210 and 220 determine the start-threshold voltage for the under-voltage protector 200. The voltage of the zener diode 220 determines the stop-threshold voltage for the under-voltage protector 200.

Referring to FIG. 3, the totem-pole buffers 50 and 55 drive the high-side circuit 60 via the capacitors 91 and 92. The capacitors 91 and 92 generate differential signals to enable high-speed switching. Two totem-pole buffers 50 and 55 produce a differential voltage across the inputs of the comparator 70. The differential voltage is produced via the two capacitors 91 and 92. The programmable load 100 uses the differential voltage to strengthen the noise immunity of the high-side circuit 60. This feature is designed to specifically for high-voltage applications. The bias voltage V_B is supplied to charge the bootstrap capacitor 30 when the low-side transistor 20 is turned on.

To further raise the floating voltage and improve the efficiency of the high-side switch driver, the differential signals are also used to charge the bootstrap capacitor 30. The differential signals charge the bootstrap capacitor 30 via the bridge-rectifier. The

under-voltage protector 200 further protects the high-side circuit 60 from an insufficient supply voltage and ensures a sufficient gate voltage level.

FIG. 6 shows a schematic circuit of a buffer, for reference purposes. This demonstrates how to build the totem-pole buffers 50 and 55, the buffers 151, 152, 153 and 290. The buffer includes two n-transistors 310 and 360, a p-transistor 350, and a current source 320. A gate of the n-transistor 310 is connected to an input of the buffer. A drain of the n-transistor 310, a gate of the n-transistor 360, and a gate of the p-transistor 350 are tied together. The current source 320 is coupled to the drain of the n-transistor 310. A drain of the p-transistor 350 and a drain of the n-transistor 360 are connected to an output of the buffer. The operation of this circuit will be well known to those skilled in the art and does not need to be discussed in further detail here.

The capacitive high-side switch driver according to the present invention can overcome many of the shortcomings of prior-art high-side switch drivers. In particular, the capacitive high-side switch driver according to the present invention is particularly well suited for use in high-voltage and high-speed applications. Some of the advantages of the capacitive high-side switch driver according to the present invention include significantly higher efficiency and strengthened noise immunity.

It will be apparent to those skilled in the art that various modifications and variations can be made to the structure of the present invention without departing from the scope or spirit of the invention. In view of the foregoing, it is intended that the present invention cover modifications and variations of this invention provided they fall within the scope of the following claims or their equivalents.